

Muon Identification in ATLAS and CMS

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Hadron Collider Physics Conference, Durham, May 2006

Outline

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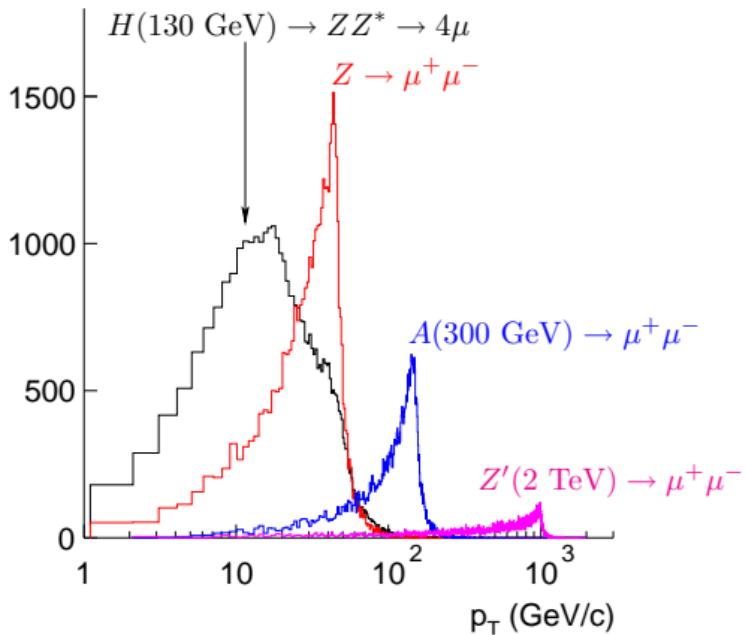
1. Introduction: Motivation and Identification Strategy.
2. The ATLAS and CMS Muon Systems.
3. Reconstruction of Muons in the Muon Systems.
4. Muon Identification at Low Transverse Momenta.
5. Status of the Muon Systems.
6. Summary.

Introduction Motivation and Identification Strategy

Role of Muons at the LHC

- Muons are the only charged primary collision products traversing the calorimeters.
→ Clean signature of muonic final states.
- Example physics processes with muonic final states:
 - $H \rightarrow ZZ^* \rightarrow \mu\mu ll,$
 - $A \rightarrow \mu\mu,$
 - $Z' \rightarrow \mu\mu.$
- Good muon identification and reconstruction is crucial for physics at the LHC.

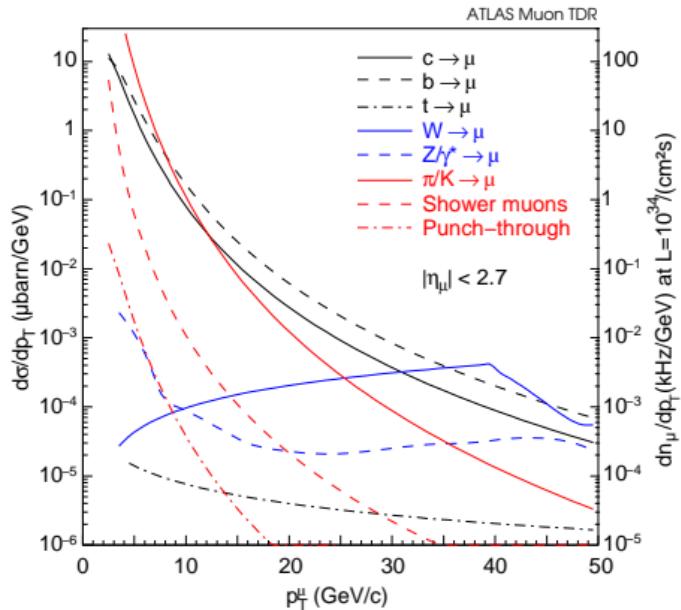
Characteristic Muon Momentum Spectra



Need for efficient muon detection and identification over wide momentum range!

Muon Identification Tasks

Inclusive muon cross sections



Muon identification tasks

- Identification of "prompt" muons from c , b , t , W , and Z/γ decays.
- Rejection of muon from π/K decays, shower muons, and hadronic punch-through.

Muon Identification Strategy

Muon identification concept

Goal	Solution
Minimization of hadronic punch-through	Muon system surrounding the calorimeters
Suppression of muons from π/K decays in flight	p_t measurement in the muon system with $\frac{\Delta p_t}{p_t} \lesssim 10\%$ + requirement of a well matching inner-detector track
Suppression of shower muons	As $\pi/K \rightarrow \mu$ + requirement of a small energy deposit in the calorimeters

The ATLAS and CMS Muon Systems

Limiting Factors of the Muon Systems

Energy loss in the calorimeters:

- Energy loss ~ 3 GeV with $\lesssim 20\%$ fluctuation.
- Larger fluctuations can be measured by the calorimeters
→ Negligible influence on $\frac{\Delta p_t}{p_t}$ for $p_t \gtrsim 10$ GeV/c.

Multiple scattering (MS) in the calorimeters:

- Negligible for ATLAS: $\frac{\Delta p_t}{p_t}|_{MS} \sim 10^{-3}$.

Multiple scattering and bending power in the muon system:

- $\frac{\Delta p_t}{p_t} \propto \frac{\sqrt{\text{material in the muon system } [X_0]}}{\int B dl}$.

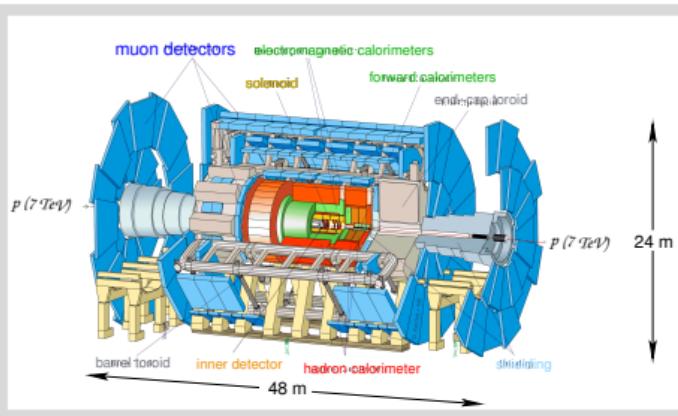
Resolution of the muon chambers:

- Spatial resolution σ of the muon chambers is the limiting factor for $\frac{\Delta p_t}{p_t}$ for high $p_t \sim 1$ TeV/c.
- $\frac{\Delta p_t}{p_t} \propto \sigma$ for $p_t \sim 1$ TeV/c.

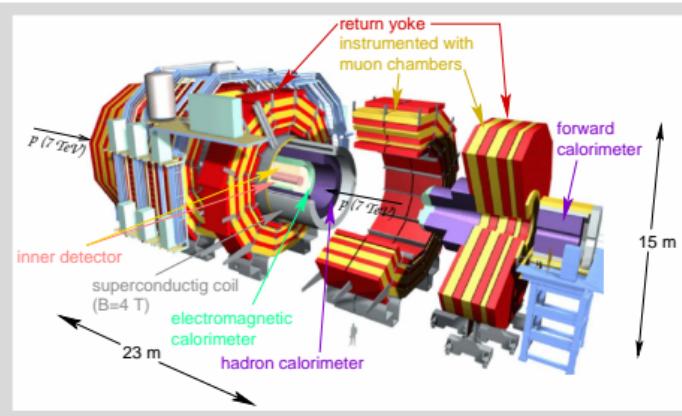
The ATLAS and CMS Muon Systems

Two concepts for the muon system

ATLAS



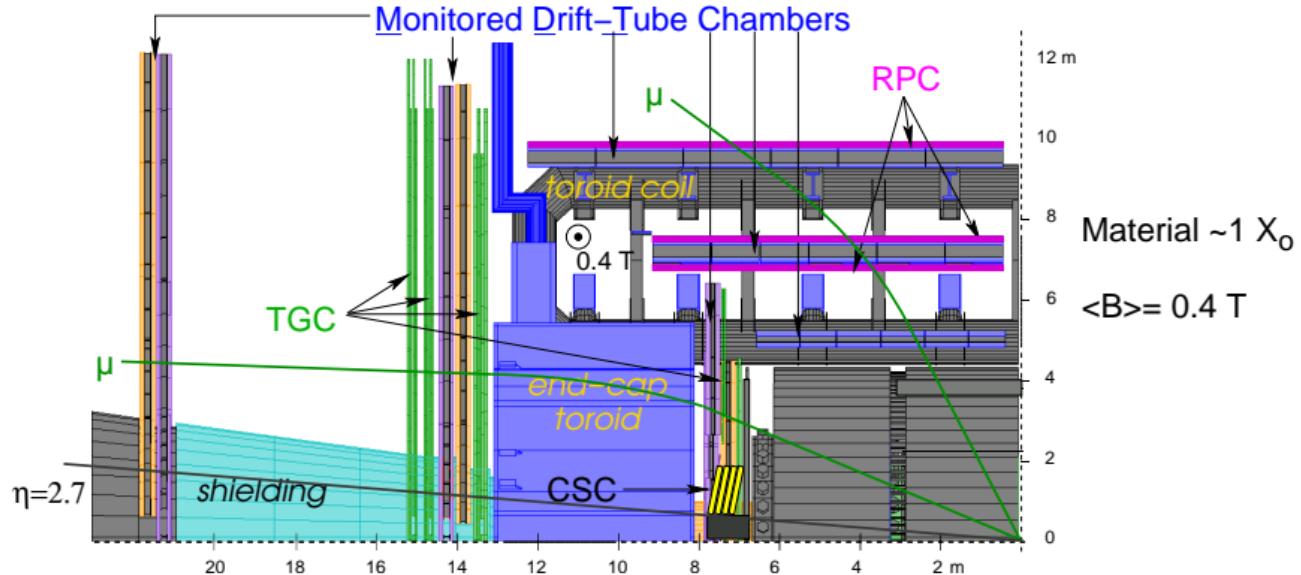
CMS



- Focus on stand-alone muon reconstruction.
- Air-core toroid → minimization of multiple scattering.

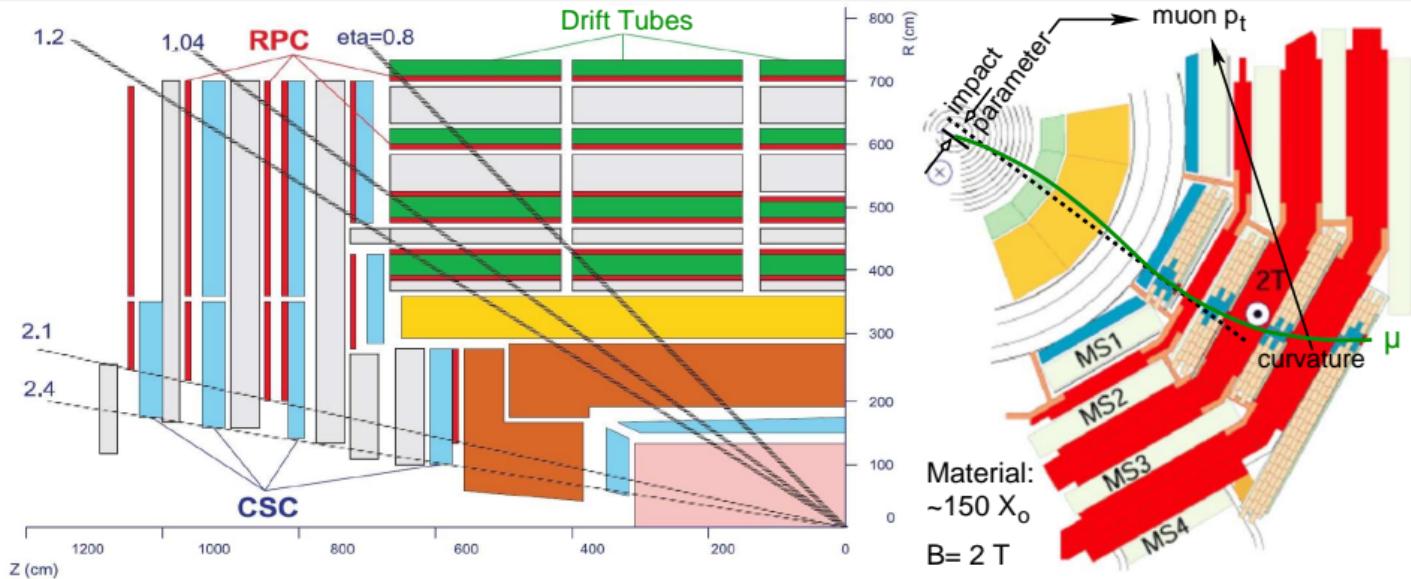
- Focus on high $\int B dl$ in the inner detector and compactness.
- Instrumented return yoke of the solenoid to achieve high bending power.

The ATLAS Muon Spectrometer



- Fast trigger chambers: **TGC, RPC** (<10 ns time resolution).
- High resolution tracking detectors: **CSC, MDT** ($40 \mu\text{m}$ spatial resolution).
- Optical alignment system with $50 \mu\text{m}$ resolution.
- Pseudorapidity coverage: $|\eta| \leq 2.7$.

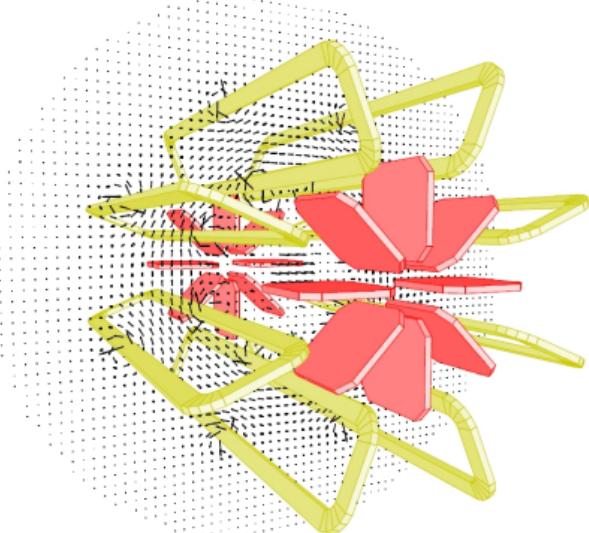
The CMS Muon Spectrometer



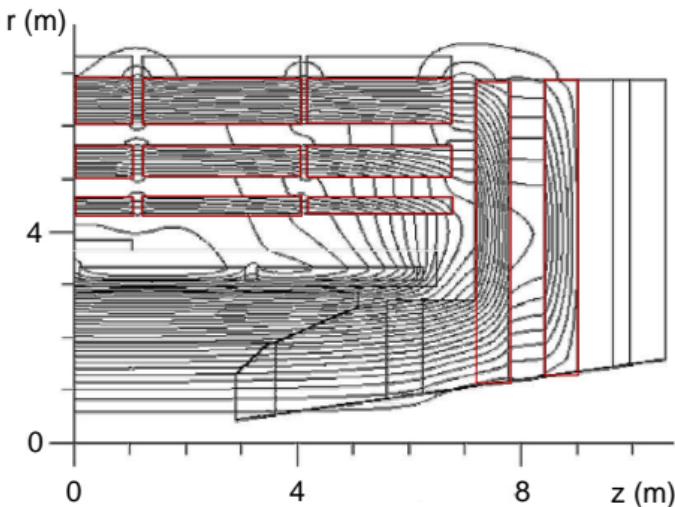
- Fast trigger chambers: **RPC** (<10 ns time resolution).
- High resolution tracking detectors: **CSC**, **DT** ($\leq 100 \mu\text{m}$ spatial resolution).
- Laser alignment of muon and inner detector with $200 \mu\text{m}$ precision.
- Pseudorapidity coverage: $|\eta| \leq 2.4$.

Magnets

ATLAS Air-Core Toroid



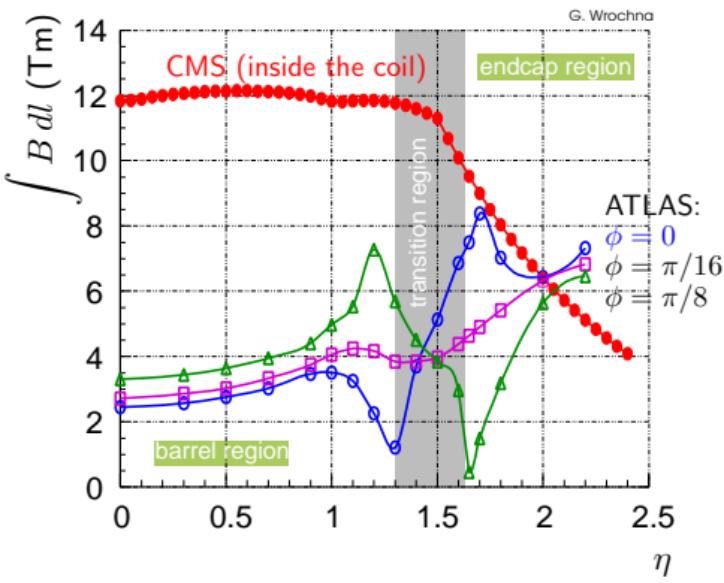
Iron Return Yoke of CMS Solenoid



- No limitation of $\frac{\Delta p_t}{p_t}$ by MS.
- Accurate B-field measurement possible.
- Uniform $\frac{\Delta p_t}{p_t}$ independent of η .

- Uniform B field in the barrel.
- High bending power.
- Limitation of $\frac{\Delta p_t}{p_t}$ by MS.
- η dependent $\frac{\Delta p_t}{p_t}$.

Comparison of the Bending Powers



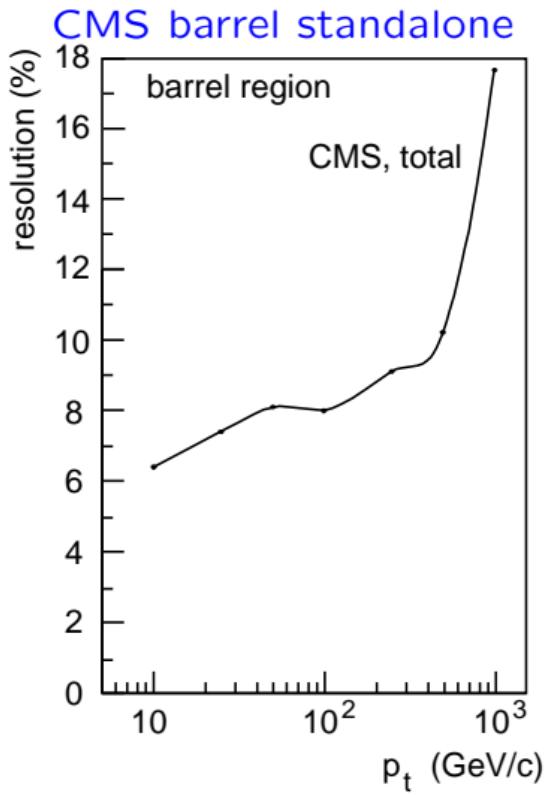
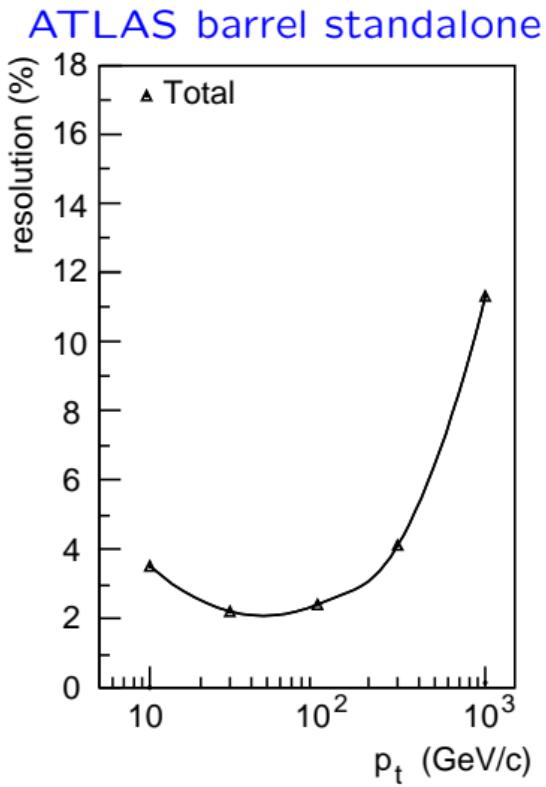
Barrel: $\approx 4\times$ higher bending power in CMS,
but $\approx 12\times$ larger multiple scattering.

→ $\approx 3\times$ worse standalone p_t resolution in CMS.

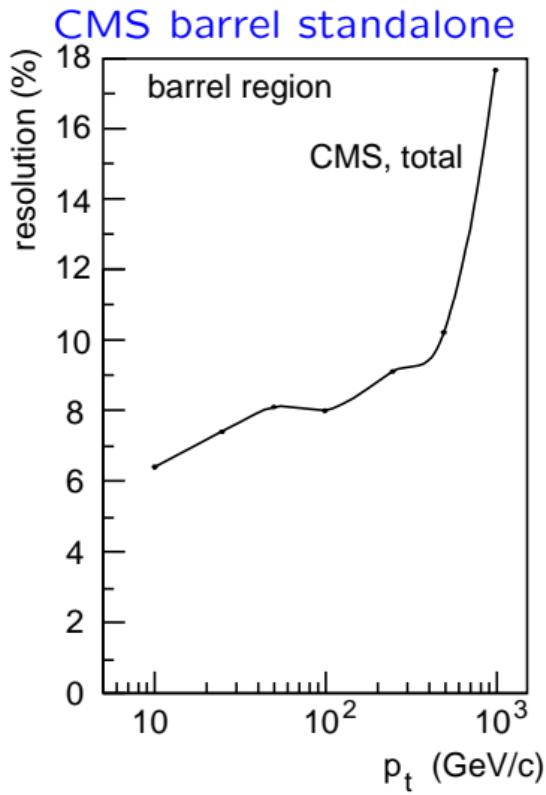
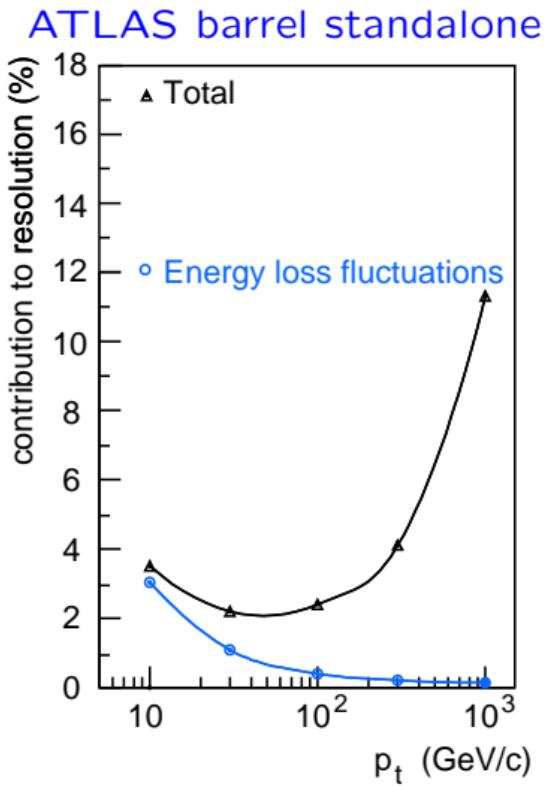
Endcap: similar bending powers,
 $\approx 10\times$ large multiple scattering.

→ $\approx 5\times$ worse standalone p_t resolution in CMS.

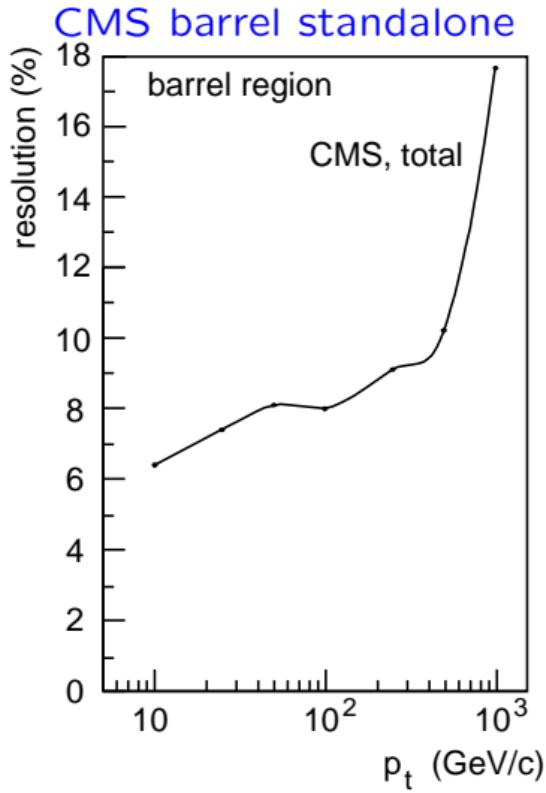
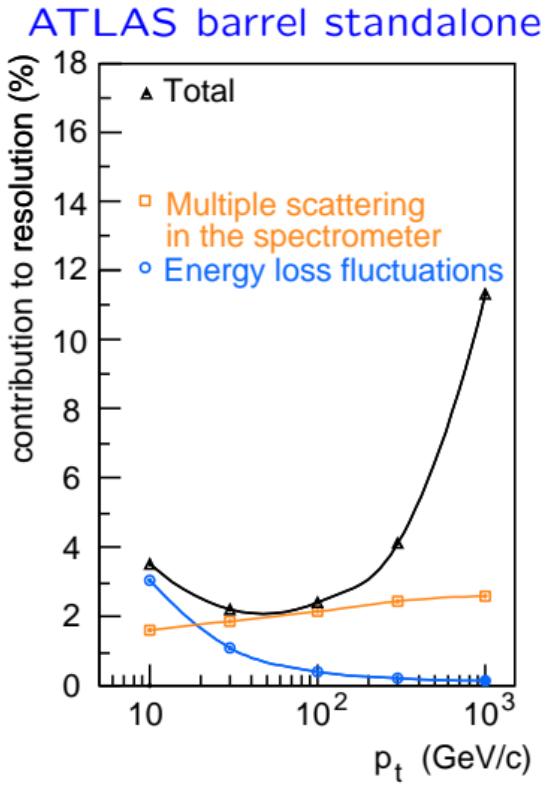
Standalone Transverse Momentum Resolution



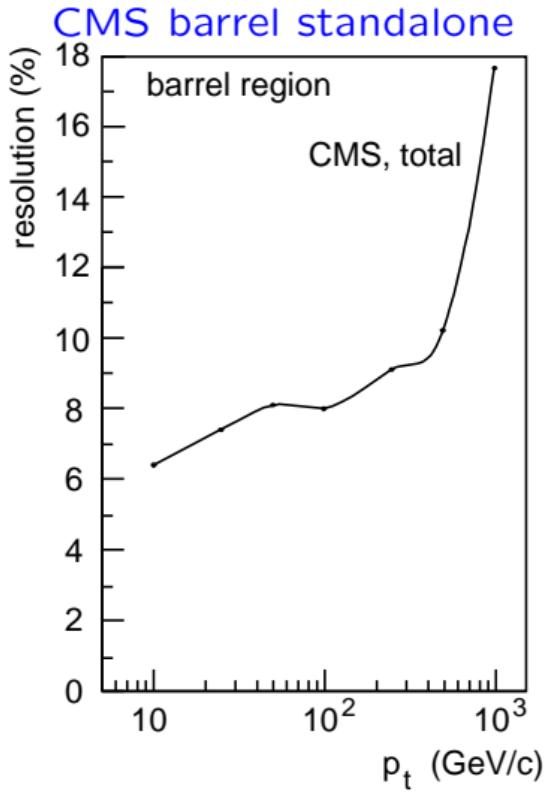
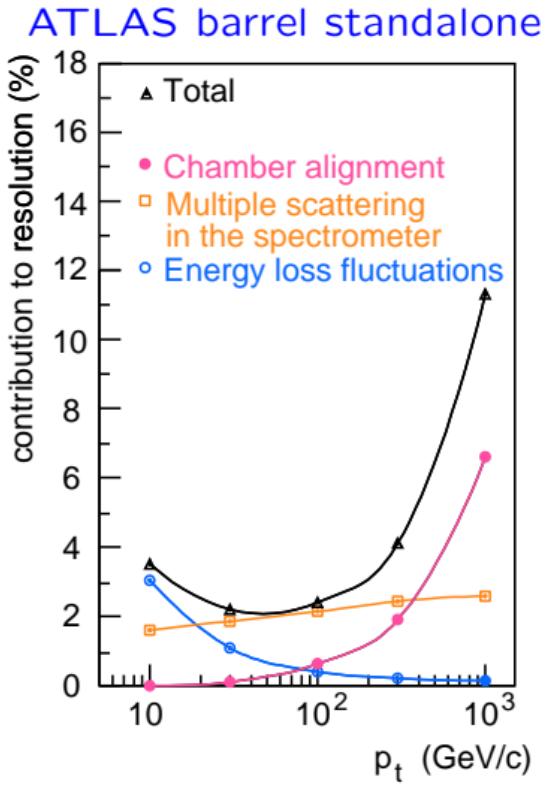
Standalone Transverse Momentum Resolution



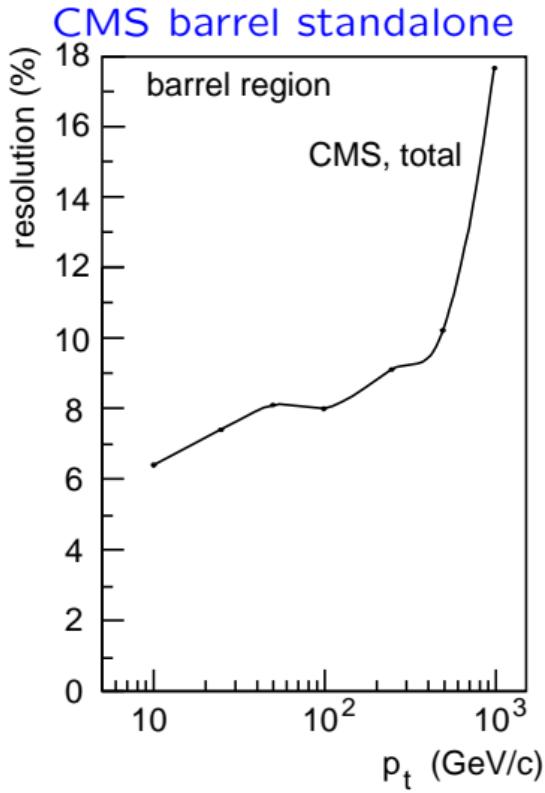
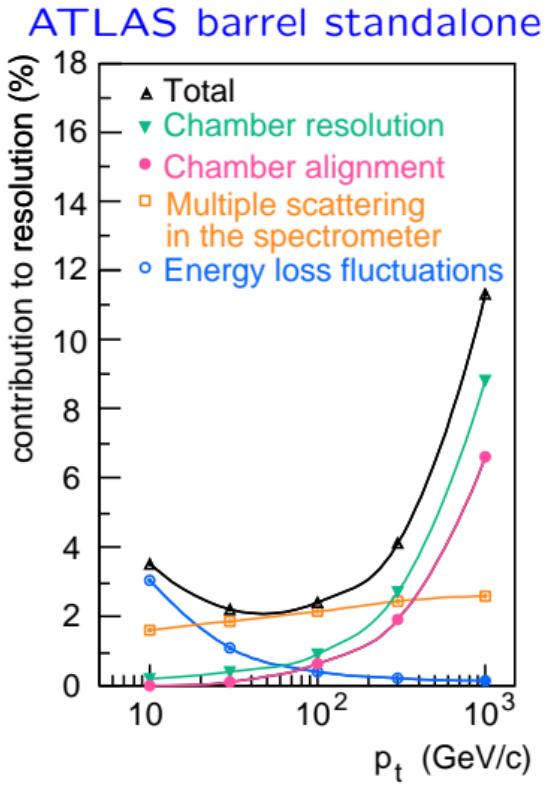
Standalone Transverse Momentum Resolution



Standalone Transverse Momentum Resolution

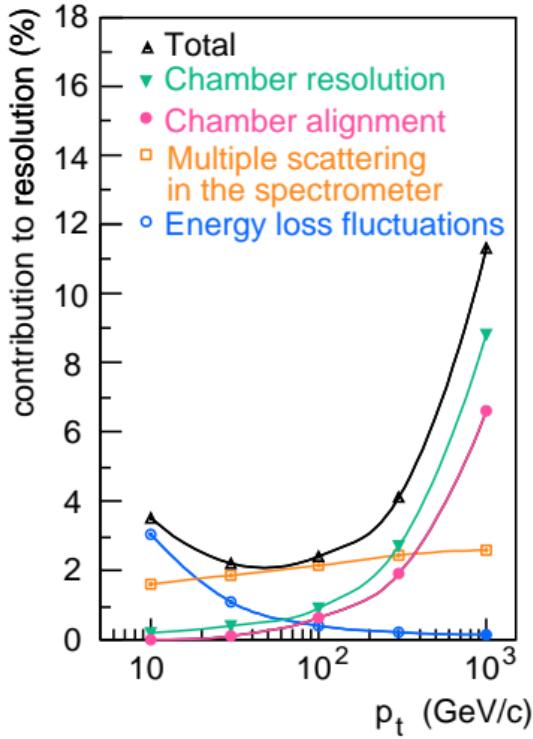


Standalone Transverse Momentum Resolution

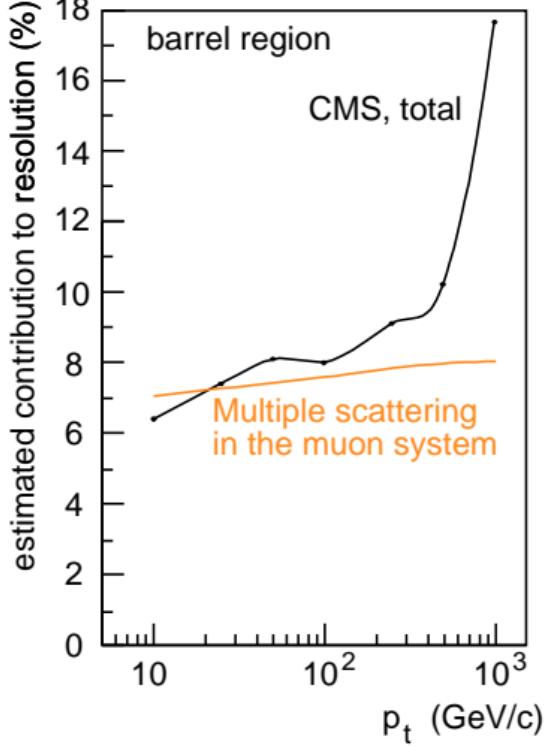


Standalone Transverse Momentum Resolution

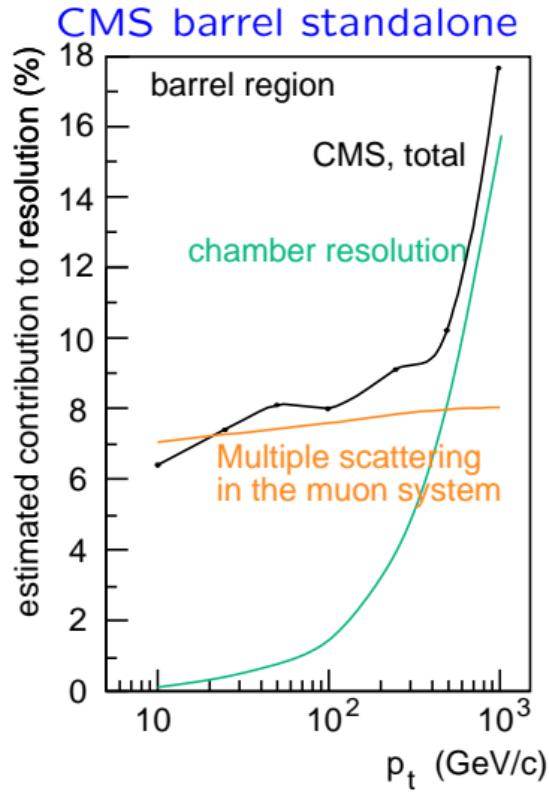
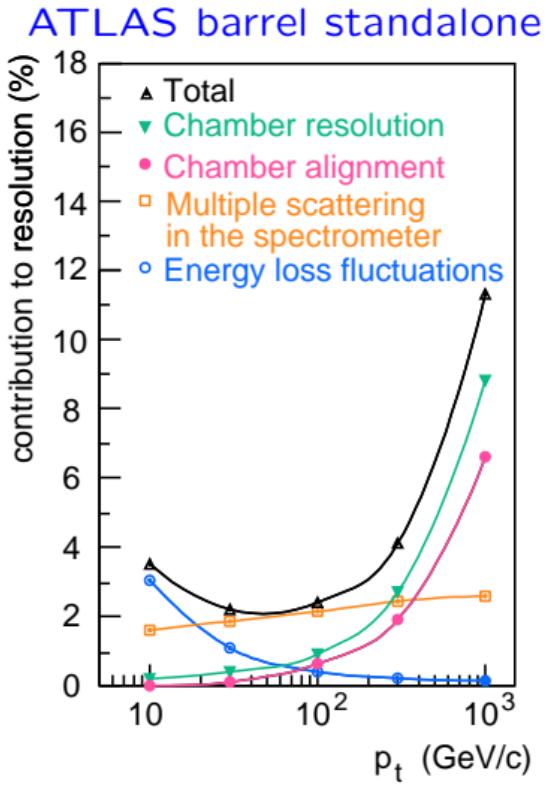
ATLAS barrel standalone



CMS barrel standalone

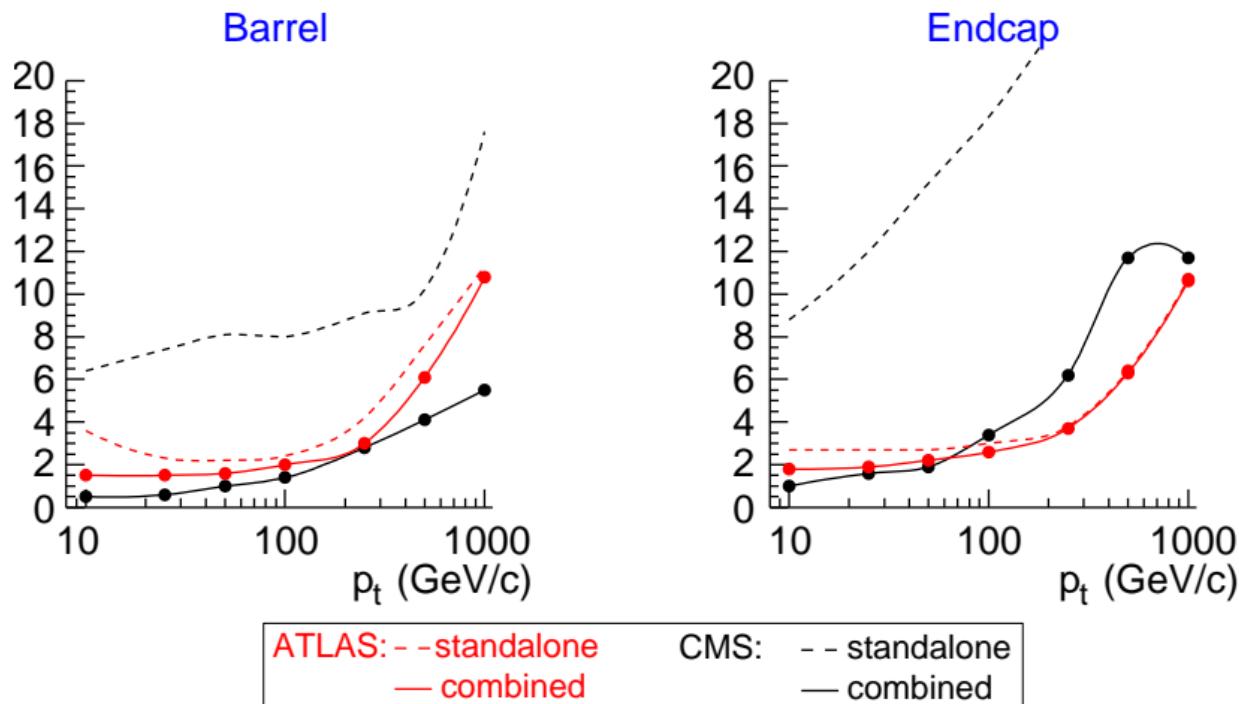


Standalone Transverse Momentum Resolution



Combined Transverse Momentum Resolution

Better resolution with muon systems and inner trackers

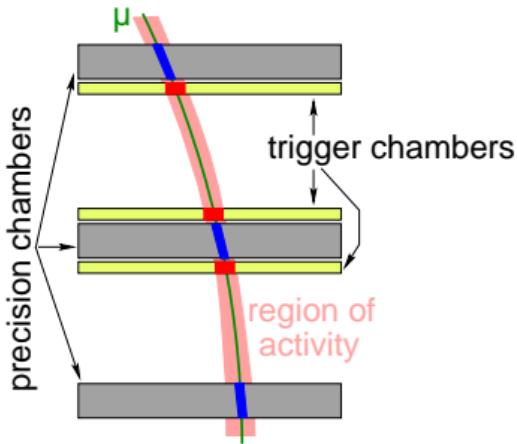


Better inner tracker resolution in CMS mainly due to higher B field.

Track Reconstruction in the Muon System

Track-Reconstruction in the Muon Systems

Both experiments reconstruct muon tracks in the following steps:



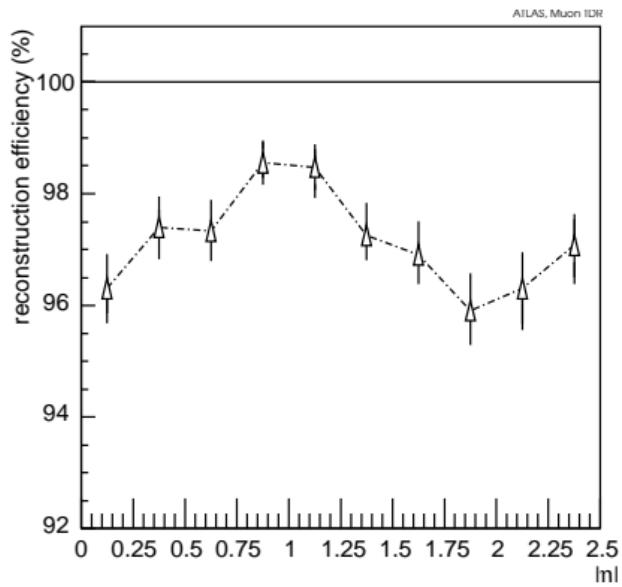
1. Definition of regions of acticity (RoA).
2. Reconstruction of local straight segments in the RoA.
3. Combination of local segments.
4. Global fit in the muon system.

Finally combination with the inner detector

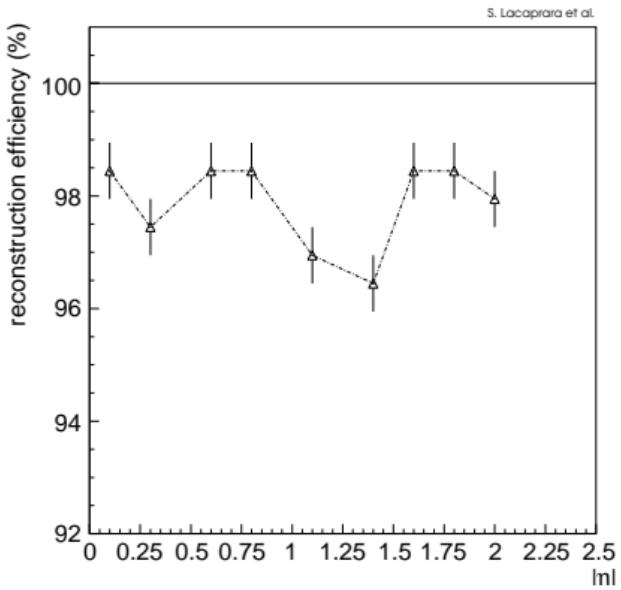
- to refine the momentum measurement,
- to identify low- p_t muons,
- to identify isolated muons.

Tracking Efficiency in the Muon Systems

ATLAS



CMS

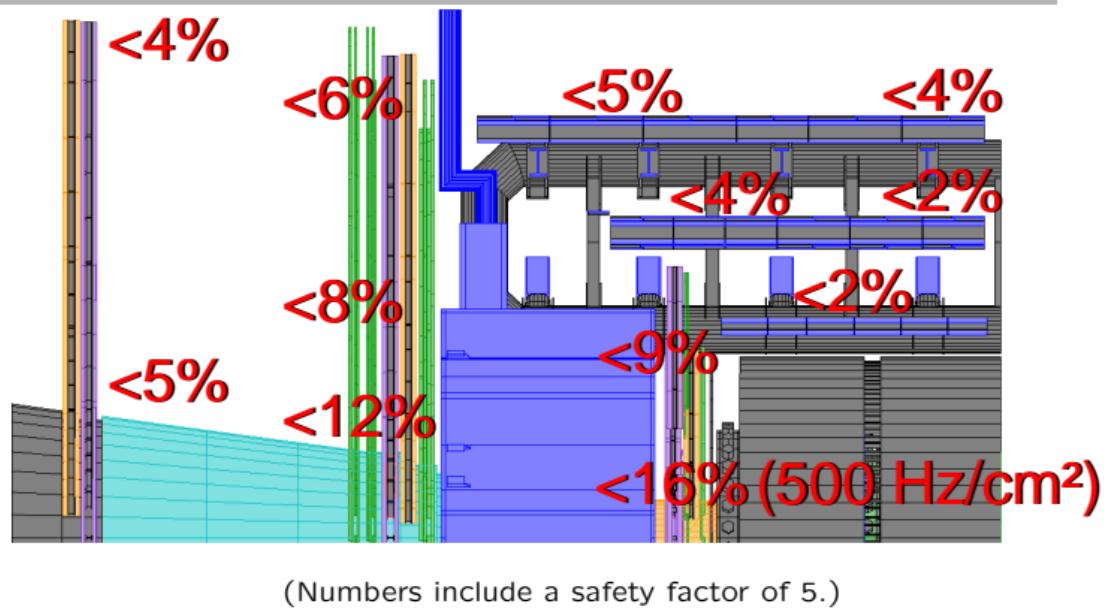


High tracking efficiency $> 96\%$ in both detectors.

Track Reconstruction in ATLAS

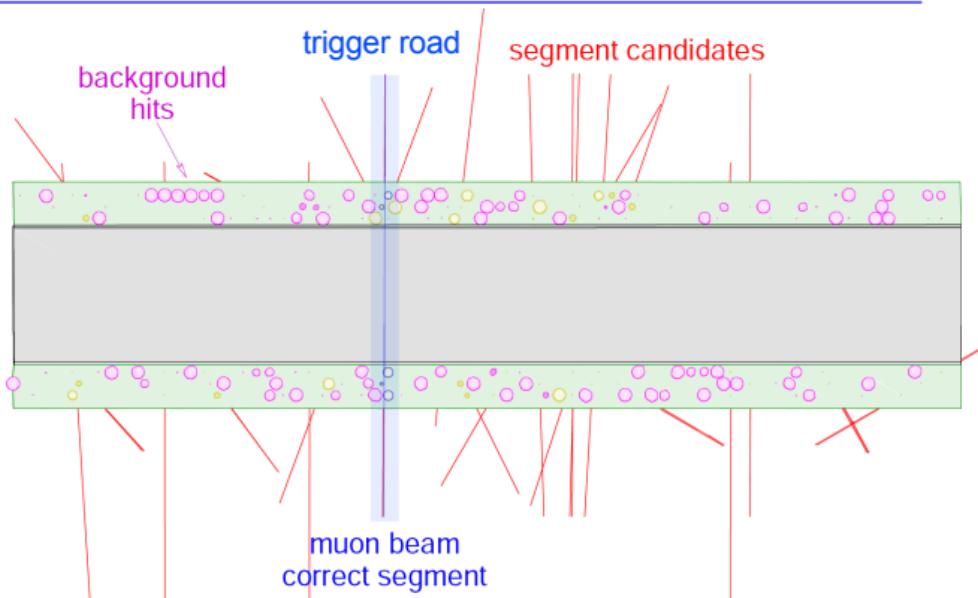
Difficulty in ATLAS: high $n - \gamma$ background.
→ High occupancy ($\sim 10 \times$ CMS).

Occupancies at $L = 10^{34} \text{ cm}^{-2} \text{ s}^{-1}$ in MDT chambers



Test-Beam Measurements

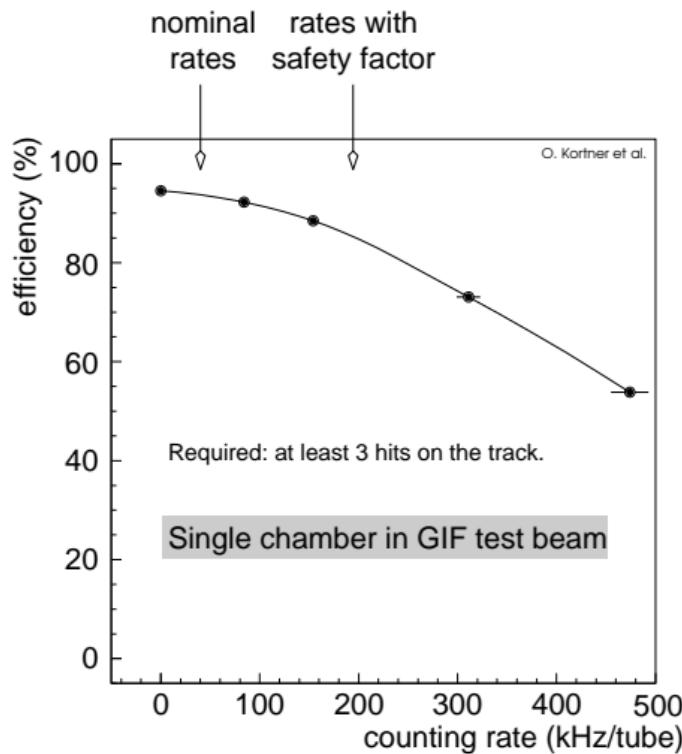
Test-beam event in the Gamma Irradiation Facility



- Muon chamber full of hits and segment candidates.
- Trigger road needed to reconstruct the correct track segment.

Test-Beam Measurements

Track-reconstruction in presence of high γ background

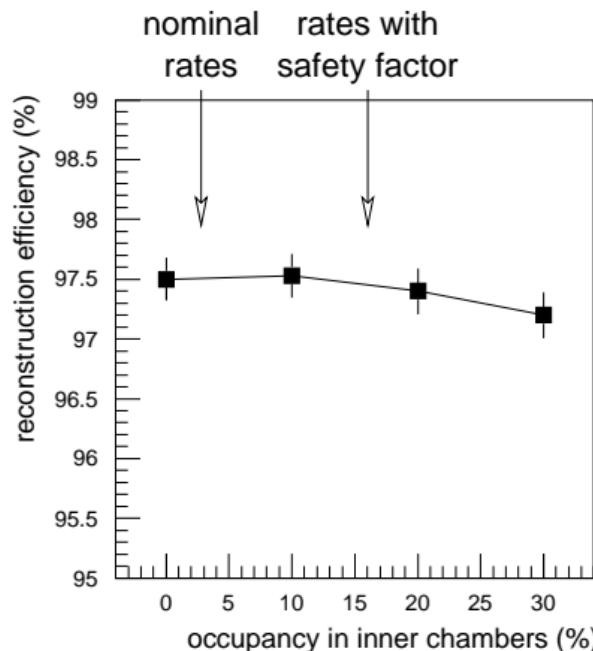


- Efficient track reconstruction for rates within safety margins!
- Significant drop of efficiency for higher rates.

Tracking in the ATLAS Muon Spectrometer

Simulation study: ATLAS Muon TDR 1999.

- Nominal occupancies in middle and outer stations.
- Variation of the occupancy in the inner station.



Results

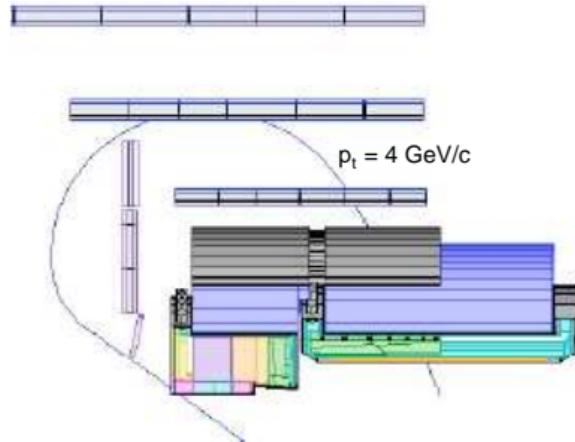
- Efficiency $> 97\%$.
- Minor efficiency degradation at highest rates.
- Fake rate $< 0.12\%$.

New studies with high background have started recently.

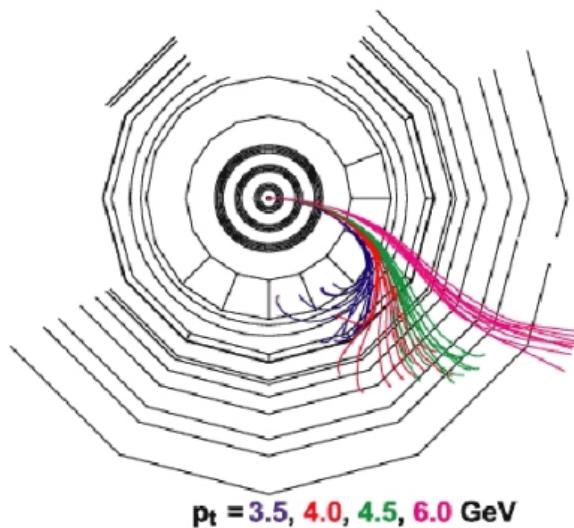
Muon Identification at Low Transverse Momenta

Muon Identification at Low Transverse Momenta

ATLAS



CMS



- Motivation: identification of soft muons in b quark jets.
- Major background: $\pi \rightarrow \mu$ (rate $\propto \frac{1}{p_t}$).
- Low energy muons do not traverse the entire muon spectrometers.
 - Only short track segments in the innermost spectrometer layers.

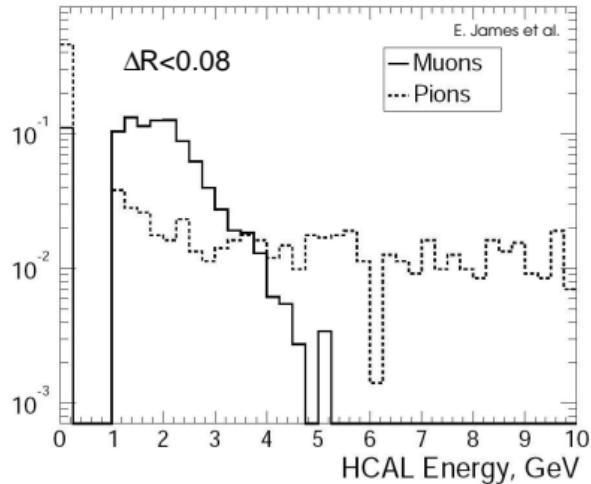
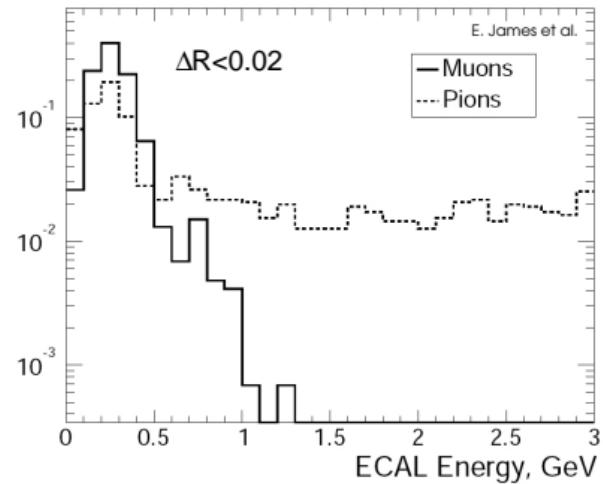
Low- p_t Identification Strategy

Muon with low transverse momentum are identified by requiring

- a inner detector track extending into the first muon-spectrometer layer,
- an energy deposit in the calorimeters in a small cone around the track compatible with the muon hypothesis,
- muon spectrometer hits/segments extending into the spectrometer as expected from the p_t of the inner-detector track ("**muon compatibility**").

Energy Deposits

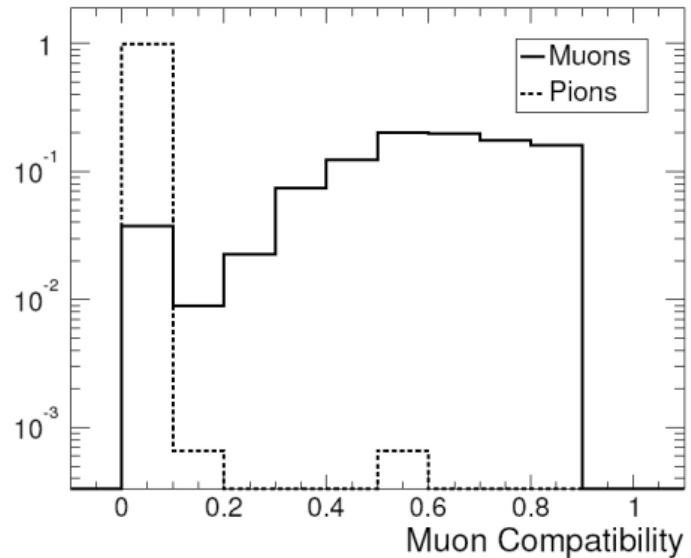
Example: $p_t=10$ GeV/c in CMS barrel.



→ Discrimination between muons and pions.

Muon Compatibility

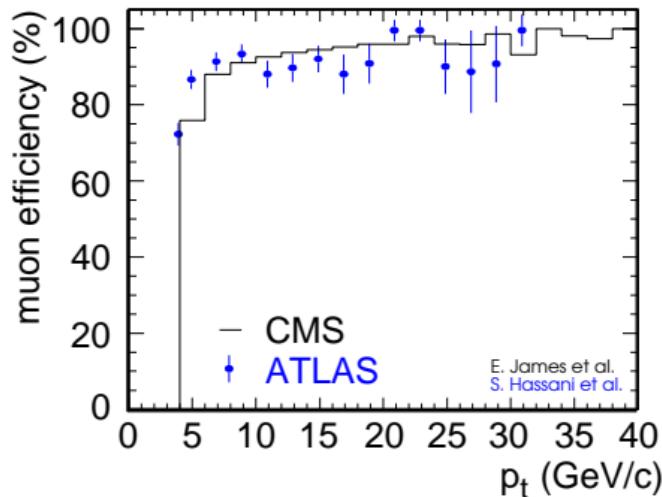
Example: $p_t = 10 \text{ GeV}/c$ in CMS barrel.



Clear separation of muons and pions.

Performance

Similar performance in ATLAS and CMS:

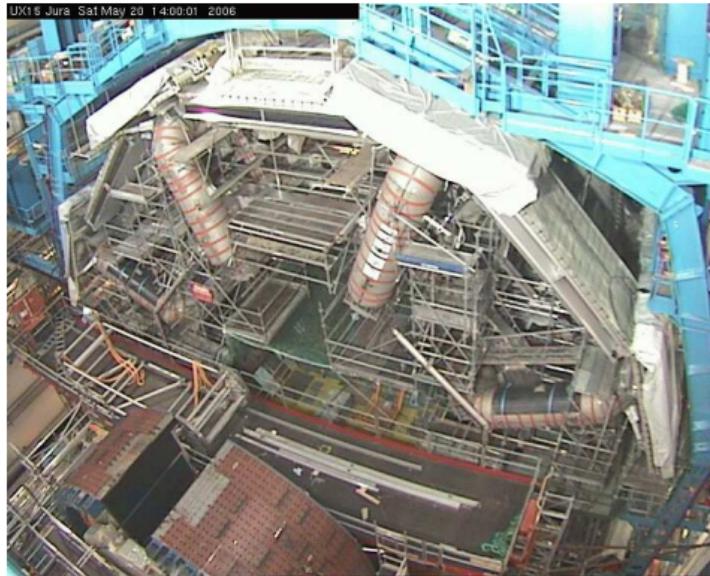


Efficiency $\sim 80\%$ for $p_t = 5 \text{ GeV}/c$.
Fake rate $< 0.5\%$ in both cases.

(low p_t + standard reconstruction)

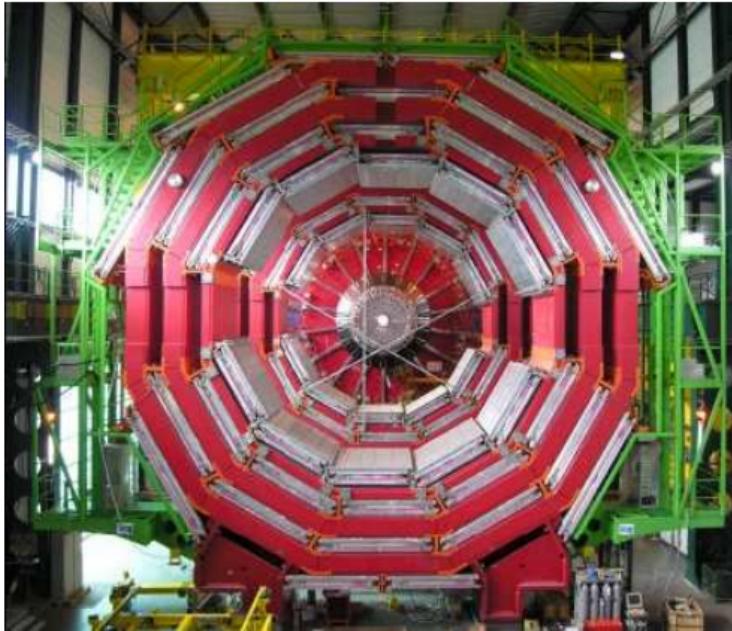
Status of the Muon Systems

Status of the ATLAS Muon Spectrometer



- Barrel installation to be completed until August 2006.
- Endcap toroid installation in fall 2006.
- Endcap installation from July 2006 until April 2007.

Status of the CMS Muon Spectrometer



- End of overground installation: fall 2006.
- Lowering and underground installation: until April 2007.

Summary

- Complementary concepts in ATLAS and CMS:

ATLAS: Standalone muon spectrometer in air-core toroid.

CMS: Instrumented return yoke of inner detector solenoid for high bending power and high momentum resolution in the inner detector.

- Transverse momentum resolution:

	p_t	standalone	combined
ATLAS:	$\leq 400 \text{ GeV}/c$	$\leq 4\%$	$\leq 2\%$
	$1 \text{ TeV}/c$	$\approx 10\%$	$\approx 10\%$
CMS:	$\leq 400 \text{ GeV}/c$	$\approx 8\%$	$\leq 1\%$
	$1 \text{ TeV}/c$	$\approx 30\%$	$\approx 10\%$

- Muon reconstruction efficiency: $> 96\%$ for $p_t > 20 \text{ GeV}/c$,
 $\approx 80\%$ for $p_t = 5 \text{ GeV}/c$.